BSM searches in $\bar{B} \to D^{(*)} \tau^- \bar{\nu}_\tau$ and rare decays at BaBar

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On behalf of
the *BABAR collaboration*

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Outline

- Introduction
- Charged Higgs searches:
  - $\bar{B} \to D^{(*)} \tau^- \bar{\nu}_\tau$ [PRL109,101802 (2012) & arXiv:1303.0571 (sub. to PRD)]
  - $B^+ \to \tau^+ \nu_\tau$ [PRD 88, 031102(R) (2013)]
- Search for $B \to K^{(*)} \nu\bar{\nu}$ and invisible quarkonium decays [PRD 87, 112005 (2013)]
- Summary and conclusions

Introduction

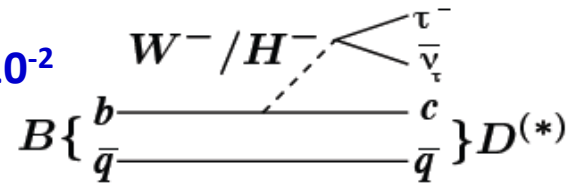
Searching for symptomatic anomalies revealing New Physics signs:
Measurements of branching fractions and kinematic observables

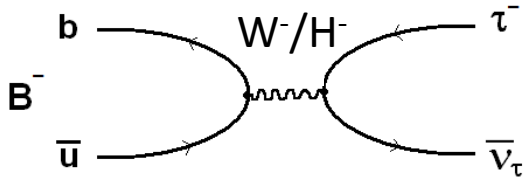
→ Have to have small theoretical uncertainties
→ Have to be experimentally accessible

Ex:

- Leptonic and semileptonic decays of B hadrons into τ leptons are sensitive to charged Higgs effects ($H^{\pm}$ coupling $\propto m_{\ell}$)

$BR_{SM} \sim 10^{-2}$

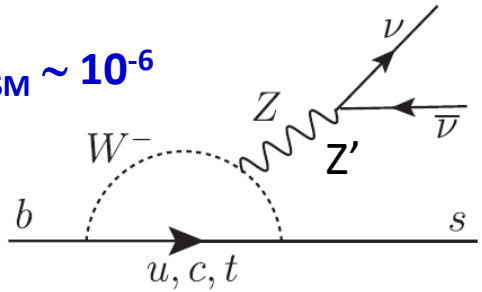




$BR_{SM} \sim 10^{-4}$

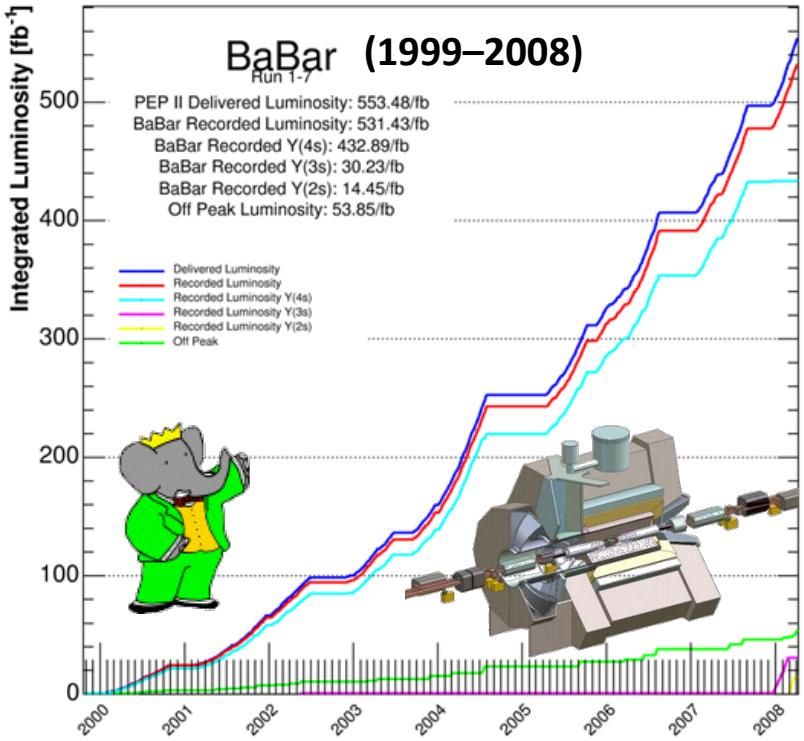
- b→s are FCNC processes, sensitive to many New Physics scenarios

$BR_{SM} \sim 10^{-6}$

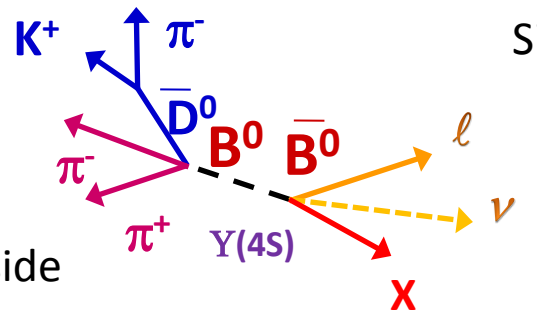


BaBar at PEP II

Asymmetric e+e- collider working (mainly) at the Y(4S) energy (10.54 GeV):
→ 426 fb^{-1} from 1999 to 2008 ~470M $B\bar{B}$ pairs



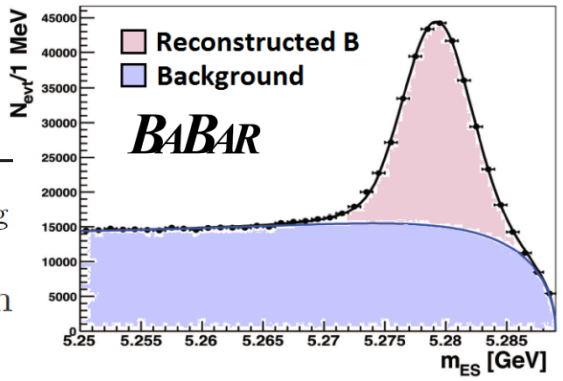
Very good tracking performance,
calorimetry and detector hermeticity
→ allow full decay reconstruction
and missing energy determination



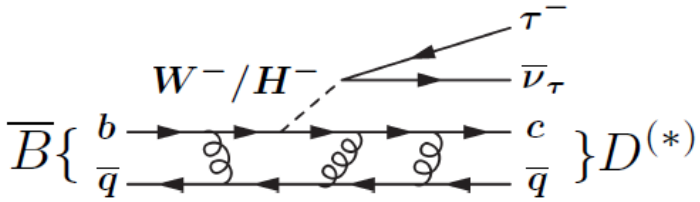
Kinematic variables:

$$m_{ES} = \sqrt{E^2_{\rm beam} - \mathbf{p}^2_{\rm tag}}$$

$$\Delta E = E_{\rm tag} - E_{\rm beam}$$



$\overline{B} \to D^{(*)} \tau^- \overline{\nu}_\tau$



- Sensitive to charged-Higgs effects
- Depends on some form factors which can be measured in $B \to D^{(*)} e/\mu\nu$ decays
- Observables: R(D) and R(D*) ratios

$$\mathcal{R}(D) = \frac{\mathcal{B}(\overline{B} \to D\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D\ell^-\overline{\nu}_\ell)} \qquad \mathcal{R}(D^*) = \frac{\mathcal{B}(\overline{B} \to D^*\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D^*\ell^-\overline{\nu}_\ell)}$$

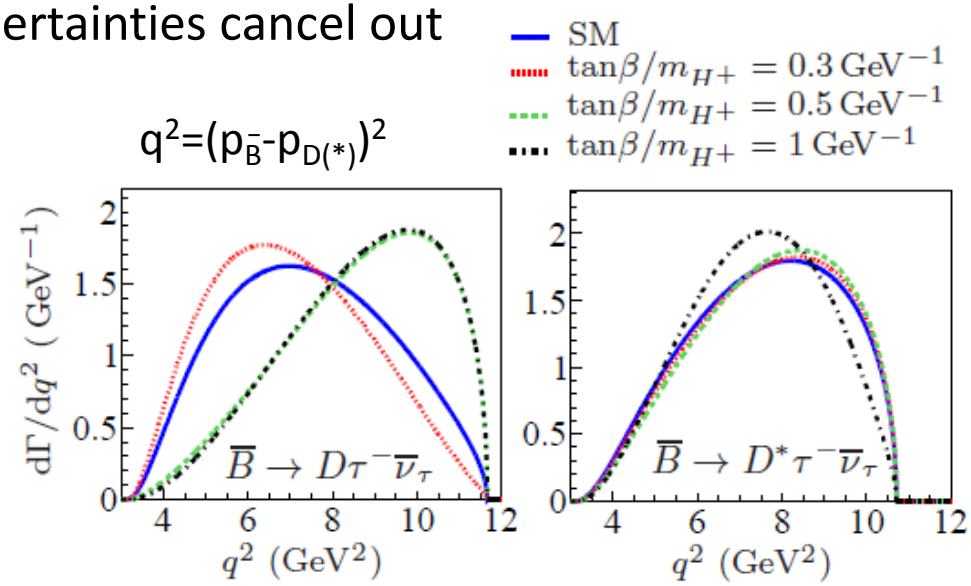
- can be enhanced by the charged-Higgs ($\tan\beta/m_{H}$)
- several systematic and theoretical uncertainties cancel out

SM predictions:

$$\mathcal{R}(D)_{\rm SM} = 0.297 \pm 0.017$$
$$\mathcal{R}(D^*)_{\rm SM} = 0.252 \pm 0.003$$

Based on HQET form factors:
[Tanaka, Watanabe: PRD82, 034027 (2010)];
[Fajfer, Kamenic, Nišandižć: PRD85, 094025 (2012)]
and experimental measurements (HFAG)

$q^2=(p_{\bar{B}}-p_{D(*)})^2$

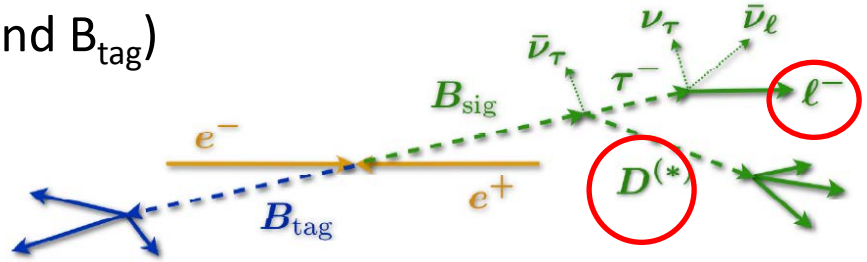


$\bar{B} \to D^{(*)} \tau^- \bar{\nu}_\tau$

[PRL109,101802 (2012) & arXiv:1303.0571 (sub. to PRD)]

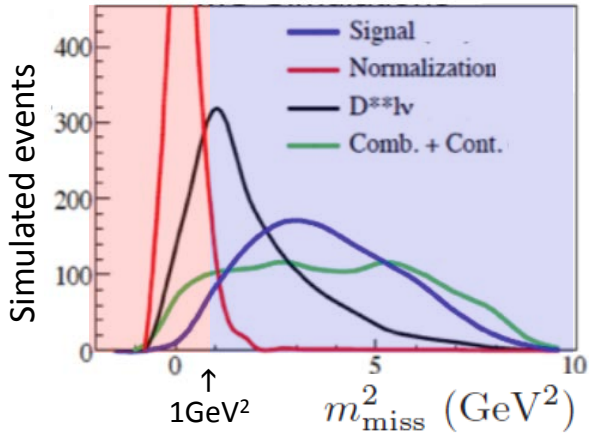
$\tau \to \mu \nu_\mu \bar{\nu}_\tau$
$\tau \to e \nu_e \bar{\nu}_\tau$

- Complete BaBar data sample
- Improved efficiencies (ℓ identification and B_{tag})
- B_{tag} fully reconstructed into hadrons
- B_{sig}: $D^{(*)}$ and lepton (μ^-, e^-)



- 4 signal samples: $(D^0, D^+, D^{*0}, D^{*+})\ell^-\bar{\nu}_\ell$ (to extract $\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$)
- 4 control samples: $(D^0, D^+, D^{*0}, D^{*+})\pi^0\ell^-\bar{\nu}_\ell$ (to derive $D^{**}\ell^-\bar{\nu}_\ell$ bkg)

$m_{miss}^2 = (p_{e+e-} - p_{Btag} - p_{D(*)} - p_{\ell^-})^2$

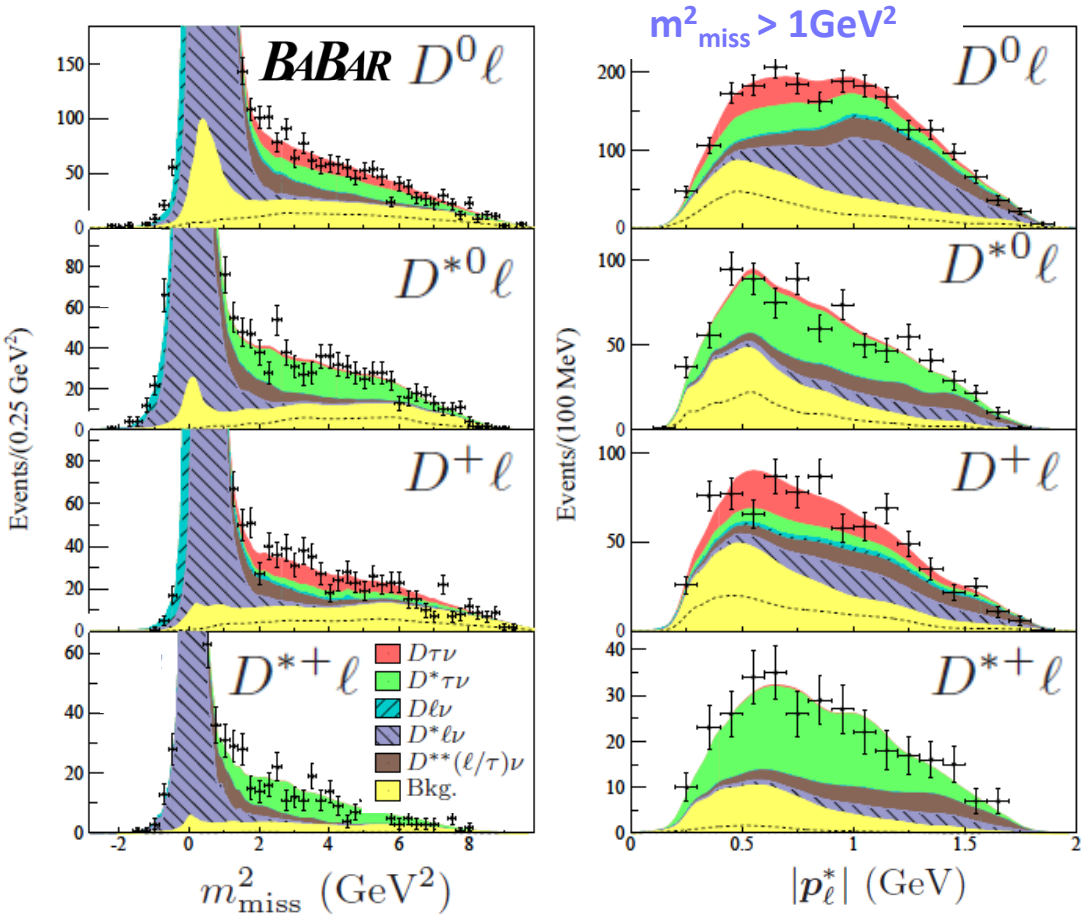


- 2D unbinned ML fit $\mathbf{m_{miss}^2\text{-}p^*_\ell}$ (3x4 parameters)
  Yields for:
  - $\bar{B} \to (D^0, D^+, D^{*0}, D^{*+})\tau^-\bar{\nu}_\tau$ (**signal**)
  - $\bar{B} \to (D^0, D^+, D^{*0}, D^{*+})\ell^-\bar{\nu}_\ell$ (**normalization**)
  - $\bar{B} \to (D^0, D^+, D^{*0}, D^{*+})\pi^0\ell^-\bar{\nu}_\ell$ (**bkg. control**)

$\longrightarrow$ **R(D) and R(D*)**

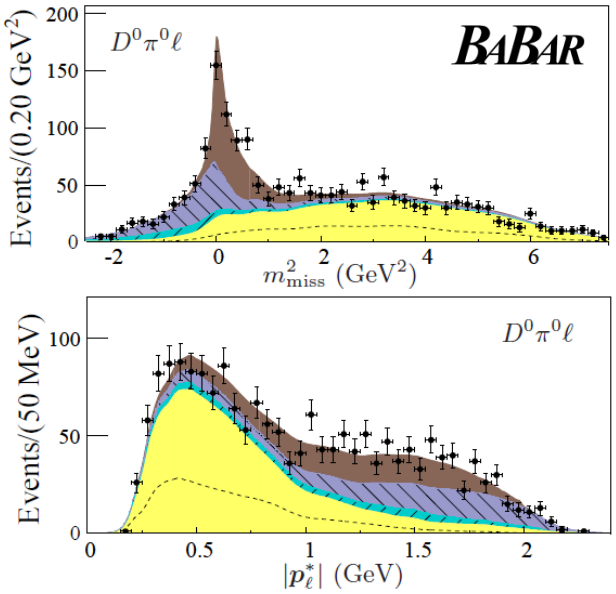
- PDF's from simulation; background corrections from data.

$\overline{B} \to D^{(*)} \tau^- \overline{\nu}_\tau$



$m^2_{miss} > 1 GeV^2$

- Main systematics related to bkg (D** fitted in the $\overline{B} \to D^{(*)} \pi^0 \ell^- \overline{\nu}_\ell$ sample)



- Results (isospin constrained):

Correlation between : R(D) and R(D*) = -0.27

Decay	$N_{\rm sig}$	$N_{\rm norm}$	$\mathcal{R}(D^{(*)})$	$\Sigma_{\rm stat}$
$\overline{B} \to D\tau^-\overline{\nu}_\tau$	489 ± 63	2981 ± 65	$0.440 \pm 0.058 \pm 0.042$	8.4
$\overline{B} \to D^*\tau^-\overline{\nu}_\tau$	888 ± 63	11953 ± 122	$0.332 \pm 0.024 \pm 0.018$	16.4

→ Large significance

$\bar{B} \to D^{(*)} \tau^- \bar{\nu}_\tau$

- Comparison with SM:

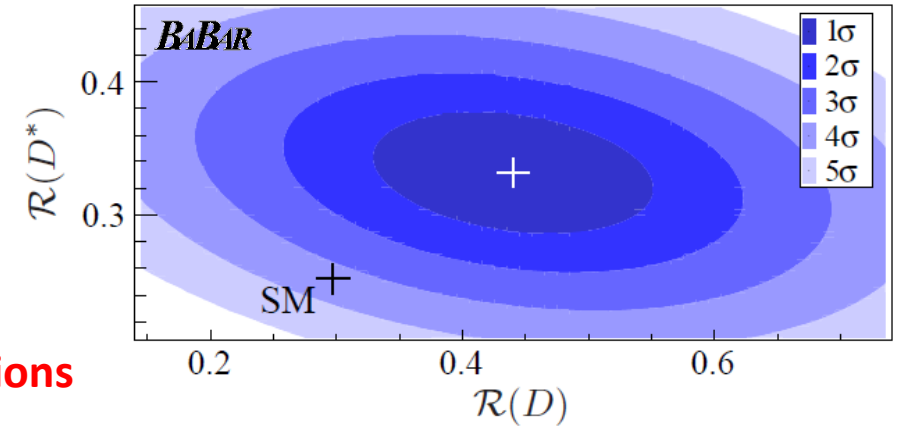
R(D)=0.440 ± 0.072

$R(D)_{SM}=0.297 \pm 0.017$ (2.0σ)

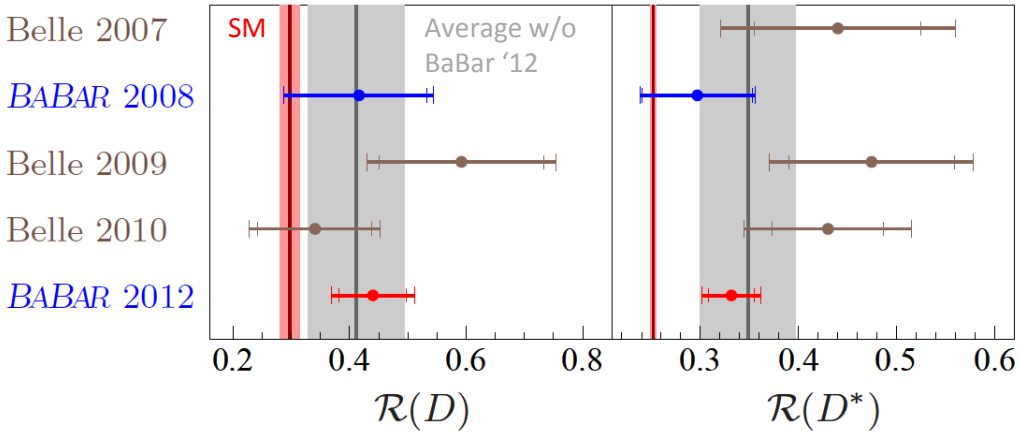
R(D*)=0.332 ± 0.017

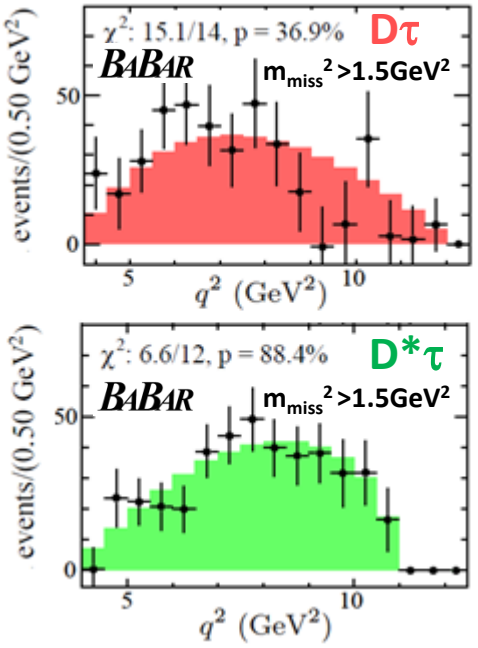
$R(D^*)_{SM}=0.252 \pm 0.003$ (2.7σ)

Combined: 3.4σ deviation from SM predictions



- Results in agreement with other measurements:





$\bar{B} \to D \tau^- \bar{\nu}_\tau$ and $\bar{B} \to D^* \tau^- \bar{\nu}_\tau$ q^2 spectra (efficiency corrected) in agreement with SM within uncertainties

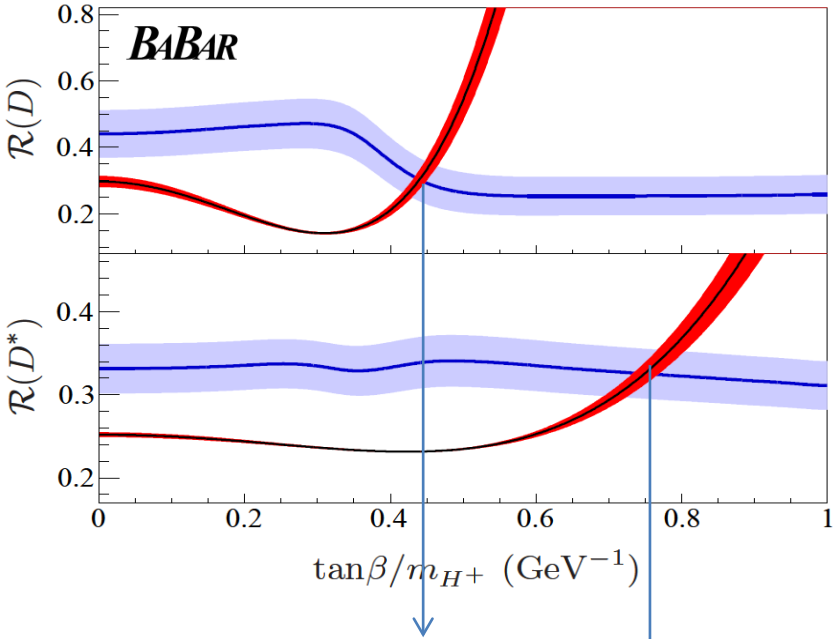
$\bar{B} \to D^{(*)} \tau^- \bar{\nu}_\tau$

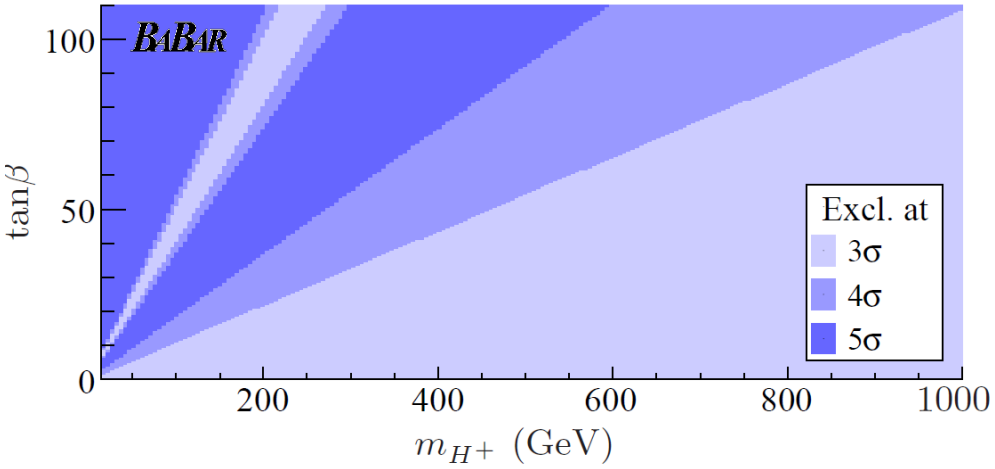
- Comparison with other models: → MSSM at tree level:

The scalar helicity amplitude in the *Two-Higgs Doublet Model* (2HDM):

$$H_s^{\mathrm{2HDM}} \approx H_s^{\mathrm{SM}} \times \left(1 - \frac{\tan^2\beta}{m_{H^\pm}^2} \frac{q^2}{1 \mp m_c/m_b}\right)$$

Type II 2HDM→ $\mathcal{R}(D^{(*)})_{\mathrm{2HDM}} = \mathcal{R}(D^{(*)})_{\mathrm{SM}} + A_{D^{(*)}} \frac{\tan^2\beta}{m_{H^+}^2} + B_{D^{(*)}} \frac{\tan^4\beta}{m_{H^+}^4}$ (Neglecting $H^\pm$ contributions in $B \to D^* \ell \nu$)





Together with $B \to X_s\gamma$ constraints, 2HDM excluded in the full $\tan\beta$-$m_{H^\pm}$ parameter space

$\tan\beta/m_{H^\pm} = 0.44 \pm 0.02$ GeV^{-1}

$\tan\beta/m_{H^\pm} = 0.75 \pm 0.04$ GeV^{-1}

Results are not compatible with a $H^\pm$ in the type II 2HDM

$\bar{B} \to D^{(*)} \tau^- \bar{\nu}_\tau$

- More general model: Type III 2HDM

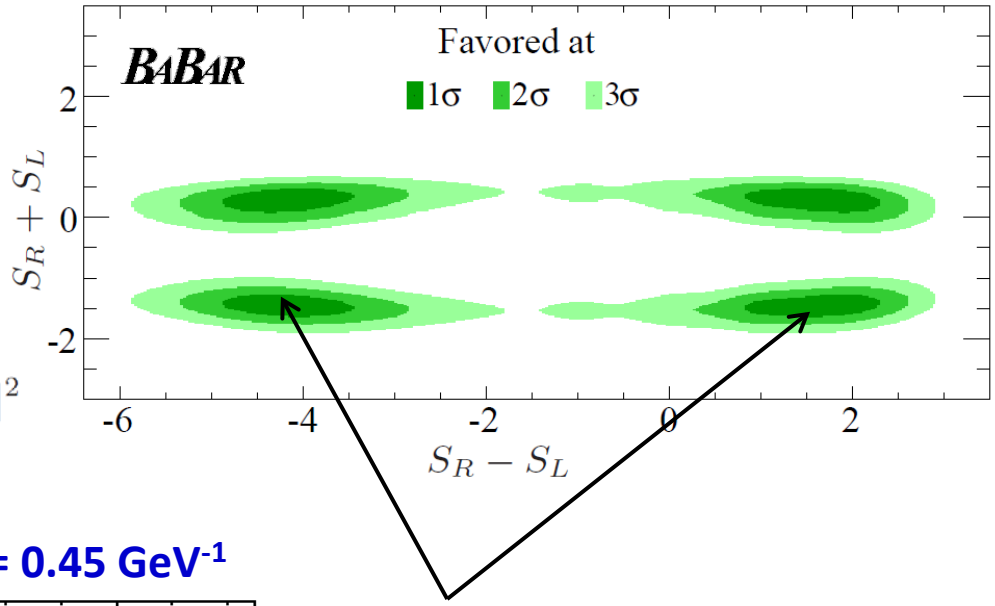
Scalar amplitude : $|H_s(S_R \pm S_L; q^2)| \propto |1 + (S_R \pm S_L) \times F(q^2)|$

with S_L,S_R complex parameters and

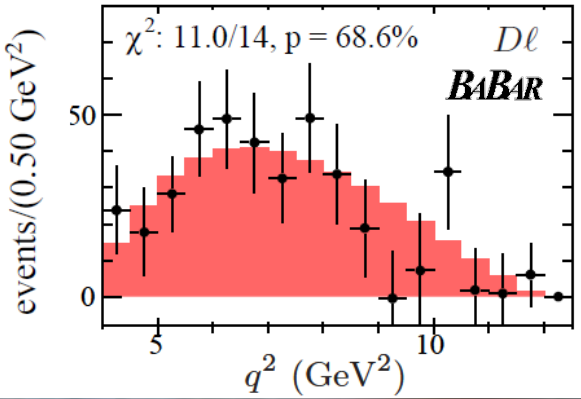
$$H_s(S_R \pm S_L) \approx H_s(-S_R \mp S_L)$$

The R(D) and R(D*) ratios:

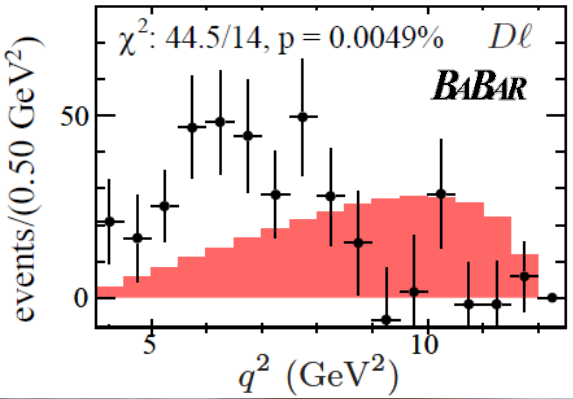
$$\mathcal{R}(D) = \mathcal{R}(D)_{\rm SM} + A'_D \mathrm{Re}(S_R + S_L) + B'_D |S_R + S_L|^2$$
$$\mathcal{R}(D^*) = \mathcal{R}(D^*)_{\rm SM} + A'_{D^*} \mathrm{Re}(S_R - S_L) + B'_{D^*} |S_R - S_L|^2$$



$\tan\beta/m_{H^\pm} = 0.30$ GeV^{-1}



$\tan\beta/m_{H^\pm} = 0.45$ GeV^{-1}



Excluded at 2.9σ by the q^2 spectrum
($\tan\beta/m_{H^\pm} = 0.45$ GeV^{-1} $\to$ $S_R + S_L \sim -1.5$)

$B^+ \to \tau^+ \nu_\tau$

- In the SM:

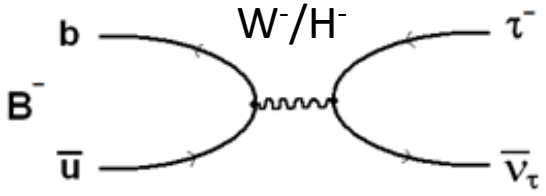
$$\mathcal{B}(B^+ \to \tau^+ \nu)_{SM} = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left[1 - \frac{m_\tau^2}{m_B^2}\right]^2 f_B^2 |V_{ub}|^2 \tau_{B^+}$$

BaBar $|V_{ub}|$ excl. $= (0.62 \pm 0.12) \times 10^{-4}$

$|V_{ub}|$ Incl. $= (1.18 \pm 0.16) \times 10^{-4}$

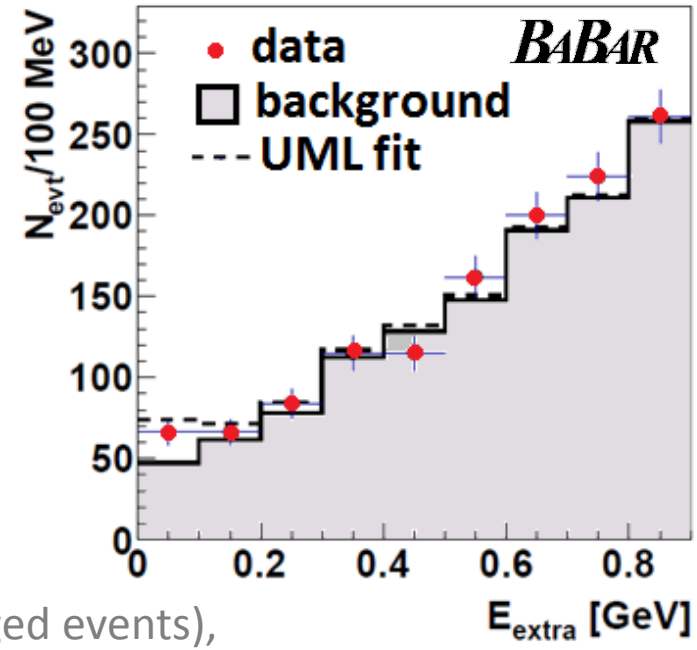
It can be altered by a charged Higgs in the 2HDM:

$$\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau)_{2HDM} = \mathcal{B}_{SM} \times \left(1 - \tan^2\beta \, \frac{m_B^2}{m_H^2}\right)^2$$



- BaBar analysis: **[PRD 88, 031102(R) (2013)]**
  - ▶ One $B_{(tag)}$ fully reconstructed into hadrons ($B^- \to D^{(*)0} X^-$ and $B^- \to J/\psi X^-$)
  - ▶ **+ 1 signal track** from the τ^+ decay **(B_{sig})** **($\tau^+ \to e^+ \nu\bar{\nu}$, $\tau^+ \to \mu^+ \nu\bar{\nu}$, $\tau^+ \to \pi^+ \nu$, $\tau^+ \to \rho^+ \nu$)**
  - ▶ Unbinned ML fit to **E_{extra}**: sum of energies of neutral clusters not associated to B_{tag}

(Signal PDF from MC (data corrected with double tagged events), combinatorial bkg. from data (m_{ES} sideband))



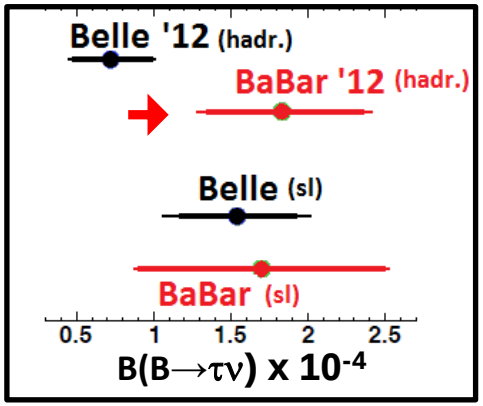
$B^+ \to \tau^+ \nu_\tau$

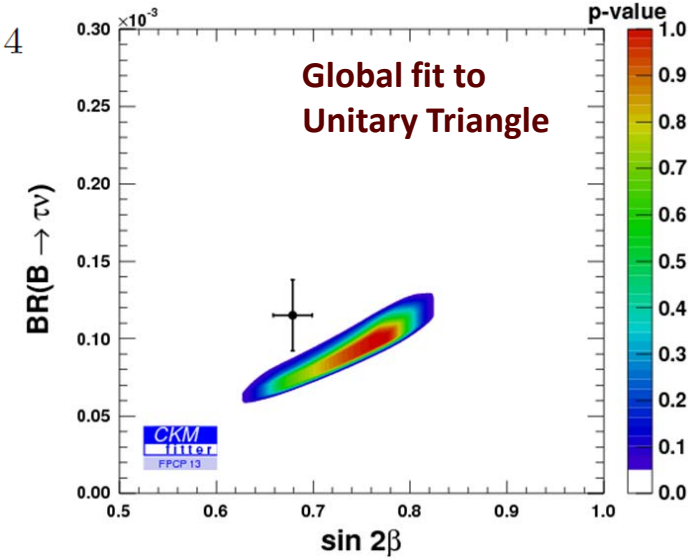
- Results:

$$\mathcal{B}(B^+ \to \tau^+ \nu) = (1.83^{+0.53}_{-0.49}(\text{stat.}) \pm 0.24(\text{syst.})) \times 10^{-4}$$

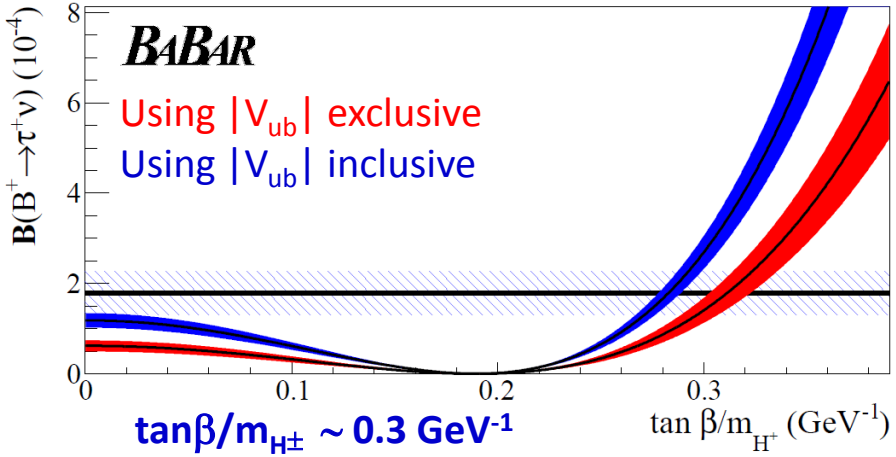
Evidence of signal at 3.8 σ

Comparison with other measurements:

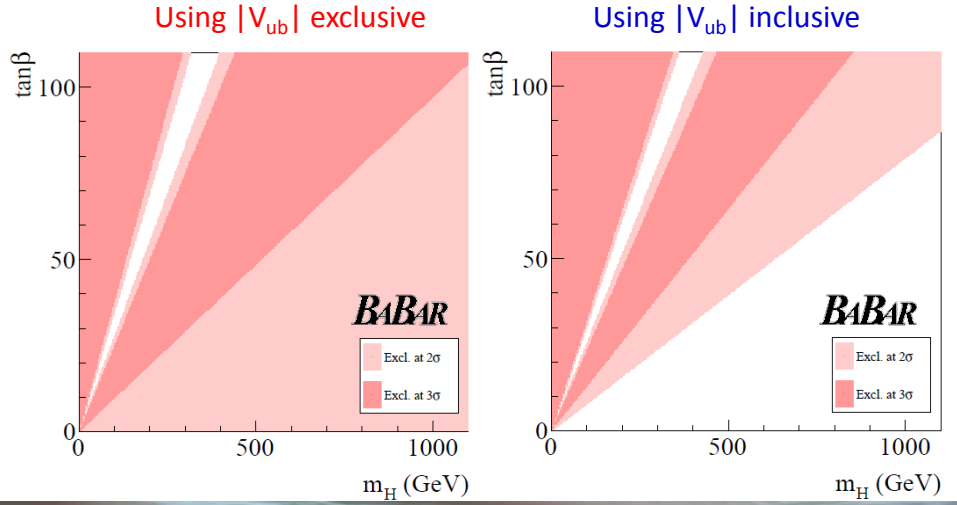




- In the 2HDM:



Exclusion regions:

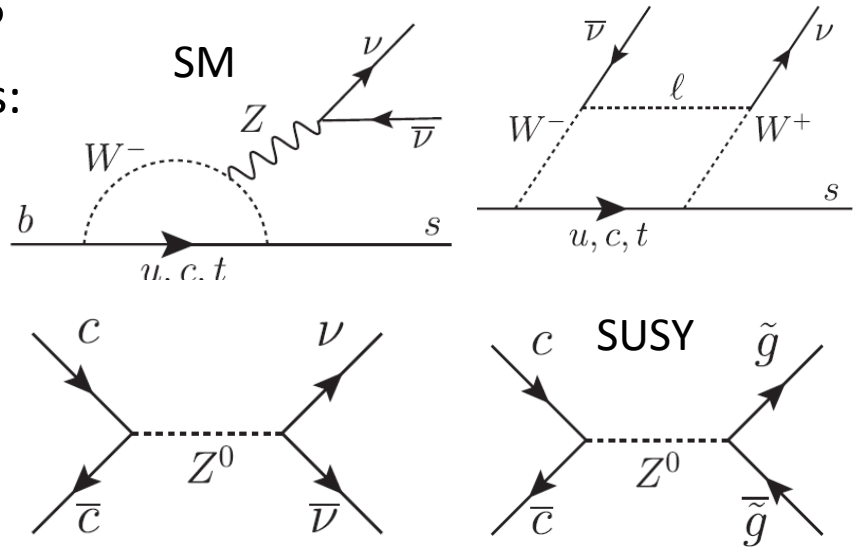


Search for $B \to K^{(*)} \nu\bar{\nu}$

- $b \to s\nu\bar{\nu}$ transitions are FCNC sensitive to NP

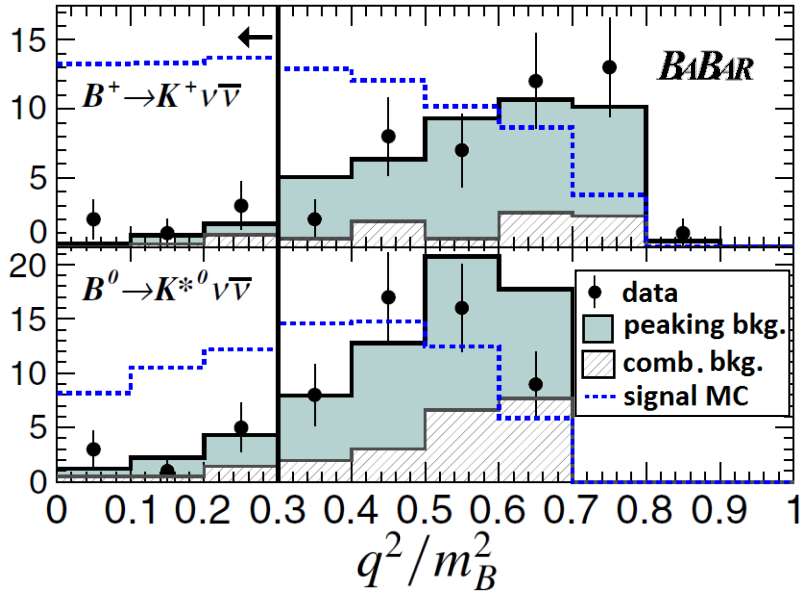
Several models predict massive new particles: non-SM Z^0,Z', 4th generation quarks… :

- $B \to K^{(*)}\nu\bar{\nu}$ via EW penguins or via resonant $c\bar{c}$ to invisible final states allow to search for BSM physics.



- BaBar analysis: **[PRD 87, 112005 (2013)]**
  - ▶ One $B_{(tag)}$ fully reconstructed into hadrons ($B \to D_{(s)}^{(*)} X^-$ and $B \to J/\psi X^-$)
  - ▶ One single reconstructed $K^{(*)}$ in the signal side ($c\bar{c} \to \nu\bar{\nu}$ with J/ψ and $\psi(2S)$)
  - ▶ Selection based on E_{extra} and specific kinematic regions to maximize SM sensitivity.

(blind analysis, $B \to D\ell\nu$ data control sample)



Search for $B \to K^{(*)} \nu\bar{\nu}$

- Results:

No significant signal → derived Upper Limits at the 90% CL:

$$\mathcal{B}(B \to K \nu\bar{\nu}) < 3.2 \times 10^{-5}$$
$$\mathcal{B}(B \to K^* \nu\bar{\nu}) < 7.9 \times 10^{-5}$$
$$\mathcal{B}(J/\psi \to \nu\bar{\nu}) < 3.9 \times 10^{-3}$$
$$\mathcal{B}(\psi(2S) \to \nu\bar{\nu}) < 15.5 \times 10^{-3}$$

Consistent with SM predicions

(First lower limit for $B^+ \to K^+ \nu\bar{\nu}$, and first upper limit for $\psi(2S) \to \nu\bar{\nu}$)

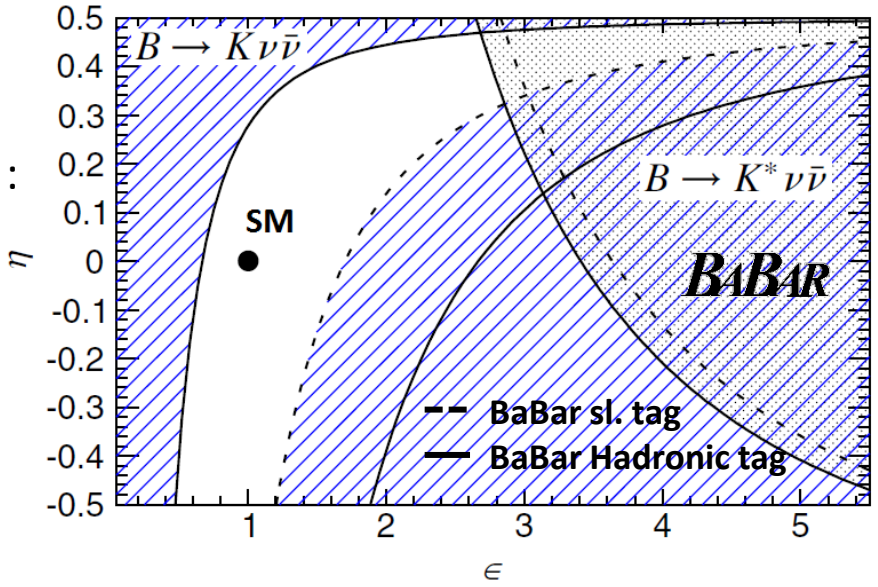
- Constraints on New Physics :

Right-handed currents,
in terms of the Wilson coefficients C^{ν}_L, C^{ν}_R :

$$\epsilon \equiv \frac{\sqrt{|C_L^\nu|^2 + |C_R^\nu|^2}}{|C_{L,\mathrm{SM}}^\nu|}$$

$$\eta \equiv \frac{-\mathrm{Re}(C_L^\nu C_R^{\nu *})}{|C_L^\nu|^2 + |C_R^\nu|^2}$$

[Altmannshofer, Buras, Straub, Wick: JHEP04,022 (2009)];



Summary and conclusions

- Measurement of R(D) and R(D*) in $\bar{B}\to D^{(*)}\tau^-\bar{\nu}_\tau$ decays

$$R(D)=0.440\pm0.072$$
$$R(D^*)=0.332\pm0.017$$

→ **3.4σ tension with the SM predictions**

→ **Exclusion of Type II 2HDM**

- Evidence for leptonic $B^+\to\tau^+\nu_\tau$ decays

$$B(B^+\to\tau^+\nu_\tau) = (1.83^{+0.53}_{-0.49}\pm0.24)\times10^{-4}$$

→ **World average in better agreement with the SM fit**

→ **Exclusion regions in $\tan\beta/m_{H^\pm}$ parameter space**

- New limits for $B\to K^{(*)}\nu\bar{\nu}$

→ **In agreement with the SM predictions**

→ **New constraints for NP scenarios**


Thank you!